Characterization of Fouled Ballast Track Demonstration with Multiple Technologies

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Agenda

• Background
• Measurements systems on DOTX 220/218
• Trackbed Moisture Mapping Sensor
• Demonstration Survey overview
• Example results at fouled ballast location
• Conclusions
Background

- FRA is utilizing and developing several inspection technologies to characterized fouled ballast, including:
  
  - Multiple vehicle-based systems on its DOTX 218/DOTX 220 comprehensive track inspection consist;
  
  - Trackbed Moisture Mapping Sensor (TMMS) developed by Vista Clara, Inc. and Zetica Rail under FRA sponsorship.

- In April 2016, FRA, in cooperation with CSX, deployed all of these in a test over territory with known fouled ballast followed a field visit to 7 selected locations to demonstrate the various approaches.
DOTX 218/DOTX 220 Comprehensive Consist

- Right of Way and Roadbed Imaging System
- Ground Penetrating Radar
- Track Geometry and Rail Profile Measurement Systems
- Gage Restraint Measurement System
- Vertical Track Deflection Measurement System
- Ride Quality Measurement System
• Developed by the University of Nebraska-Lincoln under grant from FRA; commercialized by MRail and available through Harsco Rail.
• System measures a component of the total vertical deflection of a rail.
End Cord Offset

- End Cord Offset (ECO) is calculated from the vertical space curve produced by Track Geometry Measurement System (TGMS) to eliminate the effect of the existing rail space curve profile geometry from the $Y_{rel}$ measurement.

- Defection component = $Y_{rel} - ECO$
Vertical Track Deflection Measurement System

Vertical Track Deflection Measurement System (VTDMS) installed on DOTX 218

Sensor Head
Trackbed Moisture Mapping Sensor

- Uses nuclear magnetic resonance to detect and measure moisture content; does not generate radioactive particles.
- Currently stationary use, ultimate goals to deploy on a moving platform
Survey Results

- DOTX 218/DOTX 220 surveyed predominantly Class 4 track with mix of single and double main tracks.
- Two runs each ~75 miles conducted to cover both tracks

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results, 1st Survey</th>
<th>Results, 2nd Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGMS Exceptions and Advisories</td>
<td>7 (0.09/mile)</td>
<td>3 (0.04/mile)</td>
</tr>
<tr>
<td>Rail Cant Advisory</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>GRMS Safety</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>GRMS Maintenance</td>
<td>69</td>
<td>24</td>
</tr>
</tbody>
</table>

- National average TGMS Exceptions and Advisories per mile for Class 4 track in 2015 was 0.07
Ground Penetrating Radar

- Ground Penetrating Radar (GPR) supplied by Balfour Beatty Rail / Zetica produces several metrics that characterize track:
  - Ballast Fouling Index (BFI)
  - Layer Roughness Index (LRI)
  - Ballast Thickness Index (BTI)
  - Free Draining Layer (FDL) Depth Index

- Majority of territory was shown to be moderately or highly fouled
Ballast Fouling Index (BFI) – LEFT RAIL

Seven locations between MP 67-68 identified for field follow up
Ballast Fouling Index (BFI) – LEFT RAIL

<table>
<thead>
<tr>
<th>Description</th>
<th>Count</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/a</td>
<td>498</td>
<td>4.01%</td>
</tr>
<tr>
<td>0 to &lt; 5</td>
<td>2</td>
<td>0.02%</td>
</tr>
<tr>
<td>5 to &lt;10</td>
<td>250</td>
<td>2.01%</td>
</tr>
<tr>
<td>10 to &lt;25</td>
<td>6468</td>
<td>52.07%</td>
</tr>
<tr>
<td>25 to &lt;30</td>
<td>1675</td>
<td>13.48%</td>
</tr>
<tr>
<td>&gt;30</td>
<td>3529</td>
<td>28.41%</td>
</tr>
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</table>

Table: BFI Category

<table>
<thead>
<tr>
<th>BFI Category</th>
<th>Description</th>
<th>Modelled Fouling Index (Selig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Clean</td>
<td>0 to &lt;5</td>
</tr>
<tr>
<td>4</td>
<td>Moderately Clean</td>
<td>5 to &lt;10</td>
</tr>
<tr>
<td>3</td>
<td>Moderately Fouled</td>
<td>10 to &lt;25</td>
</tr>
<tr>
<td>2</td>
<td>Fouled</td>
<td>25 to &lt;30</td>
</tr>
<tr>
<td>1</td>
<td>Highly Fouled</td>
<td>&gt;30</td>
</tr>
<tr>
<td>0</td>
<td>Unavailable</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Legend: Left rail
Example Results from Selected Individual Locations
Location #4

nominal gage

LEFT RAIL
Static profile: 3/4 in. low
rail-tie gap: 5/16 in.

RIGHT RAIL
Static profile: 1/2 in. low
rail-tie gap: 1/4 in.

Left Loaded Profile 62: 1.47 in. → exceeds Class +1
(Class 5 limit is 1.25 inches)
(Class 4 limit is 2.00 inches)
Location #5
Control location with no visual signs of fouling and no geometry deviations
Track Geometry, Deflection and GPR Results

Locations 4 and 5

L = Left Rail, C = Center, R = Right Rail

Loc. #5

Loc. #4
GRMS Results
Locations 4 and 5

Loc. #5
Loc. #4

Safety Maintenance

GW (in.)

PLG24 (in.)

Loaded Gage (in.)

Unloaded Gage (in.)

Crosslevel (in.)

Speed (mph)

Distance (Feet)
Detailed Track Geometry, Deflection and GPR for Location 4
Detected Moisture Content at Location #4

- NMR-TMMS Measurements Results - Center:

  1st scan

<table>
<thead>
<tr>
<th>Layer Depth</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-15&quot;</td>
<td></td>
<td></td>
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</table>

  2nd scan

<table>
<thead>
<tr>
<th>Layer Depth</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-15&quot;</td>
<td></td>
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</tbody>
</table>

- Repeatability decreases with depth

- Denser magnets will increase sensitivity in deeper layers
Detected Moisture Content at Location #4

Left

Right

TMMS Measurements on Shoulders
Detected Moisture Content at Location #4

- NMR-TMMS Measurements Results – track shoulders:
  - Measurement affected by position of the device extending to a portion of clean and dryer ballast beyond the edge of the ties
  - The device outputs the average water content for the measured area (1x1 meter)
Detected Moisture Content at Location #5

- **NMR-TMMS Measurements Results – center:**

```
+-----------------+-----------------+-----------------+
| Layer Depth     | Mobile Water    | Bound Water     |
|                 | Content (%)     | Content (%)     |
| 0-5"            |                 |                 |
| 5-10"           |                 |                 |
| 10-15"          |                 |                 |
+-----------------+-----------------+-----------------+
```

- Dry conditions at the surface but significant water content at depths between 5 and 15 inches.
- GPR measurement reported highly fouled ballast at this location despite visually clean surface
Results

• This effort demonstrated the capabilities of a variety of track inspection technologies to characterize fouled ballast locations.

• The test showed that overall good track geometry was maintained at the surveyed territory despite a compromised quality of the ballast.

• It was determined during the field investigation that track surface deviations at locations visited were a result of vertical movement under load due to compromised track support conditions.

• The apparent vertical movement, however, was not exhibited by VTDMS data. Current FRA research efforts are directed at further understanding of vertical track deflection measurements.
Results

- Highly repeatable NMR-TMMS measurements of water content held in fouled ballast materials were demonstrated up to a depth of 15 inches with a total scan time of 7.5 minutes at each site.

- NMR-TMMS measured volumetric water content in the ballast materials of the seven investigated locations ranged between 6% and 17%.

These levels appear reasonable given the near-complete saturation of the inter-ballast pore space observed at the locations.
Next Steps

• FRA in cooperation with Harsco is upgrading VTDMS system on the DOTX 218

• FRA plans to conduct another test over a territory with known fouled locations

• Vista Clara and Zetica are working on improvement to the NMR-TMMS device
  • New array with 50% increase in magnet density constructed
  • Expected to double the sensitivity of the measurement in depths between 10 and 20 inches
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